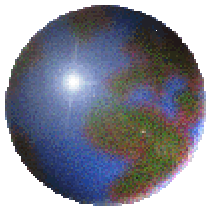
Crystal Collimation at RHIC



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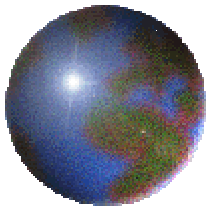
Collaboration



BNL, Upton, NY

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- Dave Gassner
- Lee Hammons
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IHEP, Protvino

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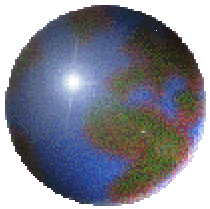
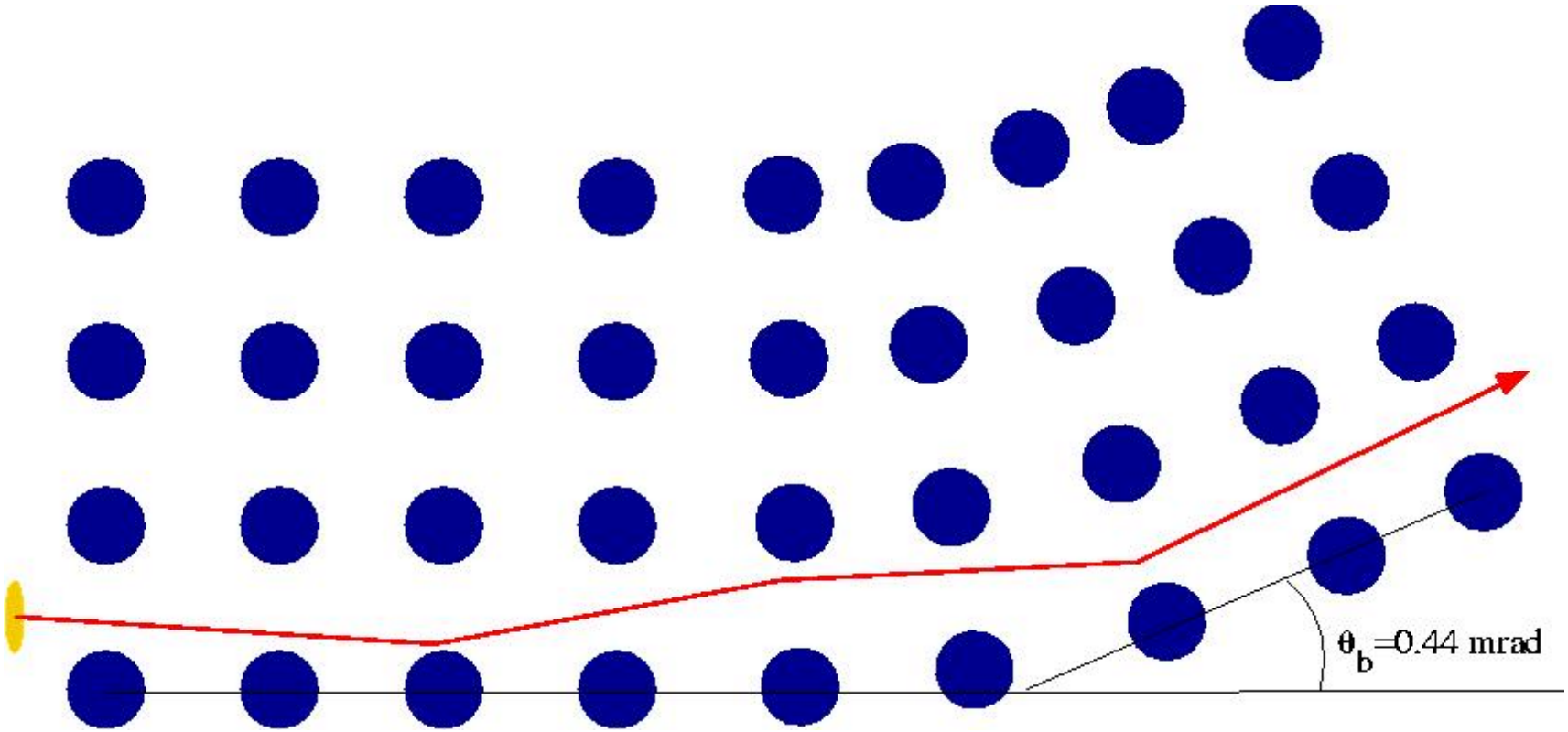
Crystal Channeling



Crystal Channeling



If particles entering a crystal are properly aligned to the crystal planes, they will follow the planes, even if the crystal is bent.

How channeling works

Particles entering a crystal with small angles will see the crystal structure. If they move fast enough, the individual atomic potentials are smeared together into a transverse inter-planar potential, U(x). As long as the kinetic energy of the transverse motion is small compared to the maximum interplanar potential $U(x_c)$, then the particle is channeled.

$$\frac{p_{t_{max}}^2}{2m} \mathrm{d}\ U(x_c)$$

x_c is the location where the particle will enter the lattice plane electron cloud, p_t is the transverse momentum.

The Critical Angle

This gives an upper limit for the incident angle

$$\theta_c = \sqrt{\frac{2U(x_c)}{pv}}$$

p is the momentum of the incident particle,
v is the velocity

θ_c is the critical angle. For RHIC:

$\theta_c = 37\ \hat{A}\ rad$ at injection

$\theta_c = 11\ \hat{A}\ rad$ at store

Effect of the Beam Optics

Assuming a particle distribution

$$Ç(J,°) = \frac{1}{\sqrt{2 ÆÈ_p »}} \exp\left(\frac{□ J}{»}\right) \exp\left(\frac{□ °^2}{2 È_p^2}\right)$$

ε = unnormalized emmittance J = particle action

σ_p = rms momentum deviation δ = momentum deviation

By writing J=J(x,x',δ), and integrating over δ, it is possible to construct the particle distribution ρ(J,δ)=ρ(x,x'). This can be used to compute the angle of the crystal with respect to the orbit to achieve channeling (channeling angle), the angular width of the channeling distribution, and channeling efficiency.

Channeling Equations

Channeling angle: ¾= $x_{crystal}$ □ · »ƒ DD'È^{2}˚ ¸ »ƒ D^{2}È^{2}˚

$x_{crystal}$ is the distance between the crystal face and the beam orbit.

The width of the channeling dip σ is highly dependant on the average impact parameter of the particles *dx*, α , β, and Dσ . The expression for is quite complicated, and not displayed.

θ δ

From Equation 2.12 in *Crystal Channeling and Its application to High Energy Accelerators* the channeling efficiency is

$$e = \frac{2x_{c}}{d_{p}} \frac{Æ}{4} \frac{¾_{c}}{È\,¾}$$

Placing the crystal at a place with a large α or D' means:

- The channeling angle depends strongly on crystal position
- The width of the channeling is increased.
- The channeling efficiency is reduced because of the increased width.
- Increased sensitivity to lattice errors.

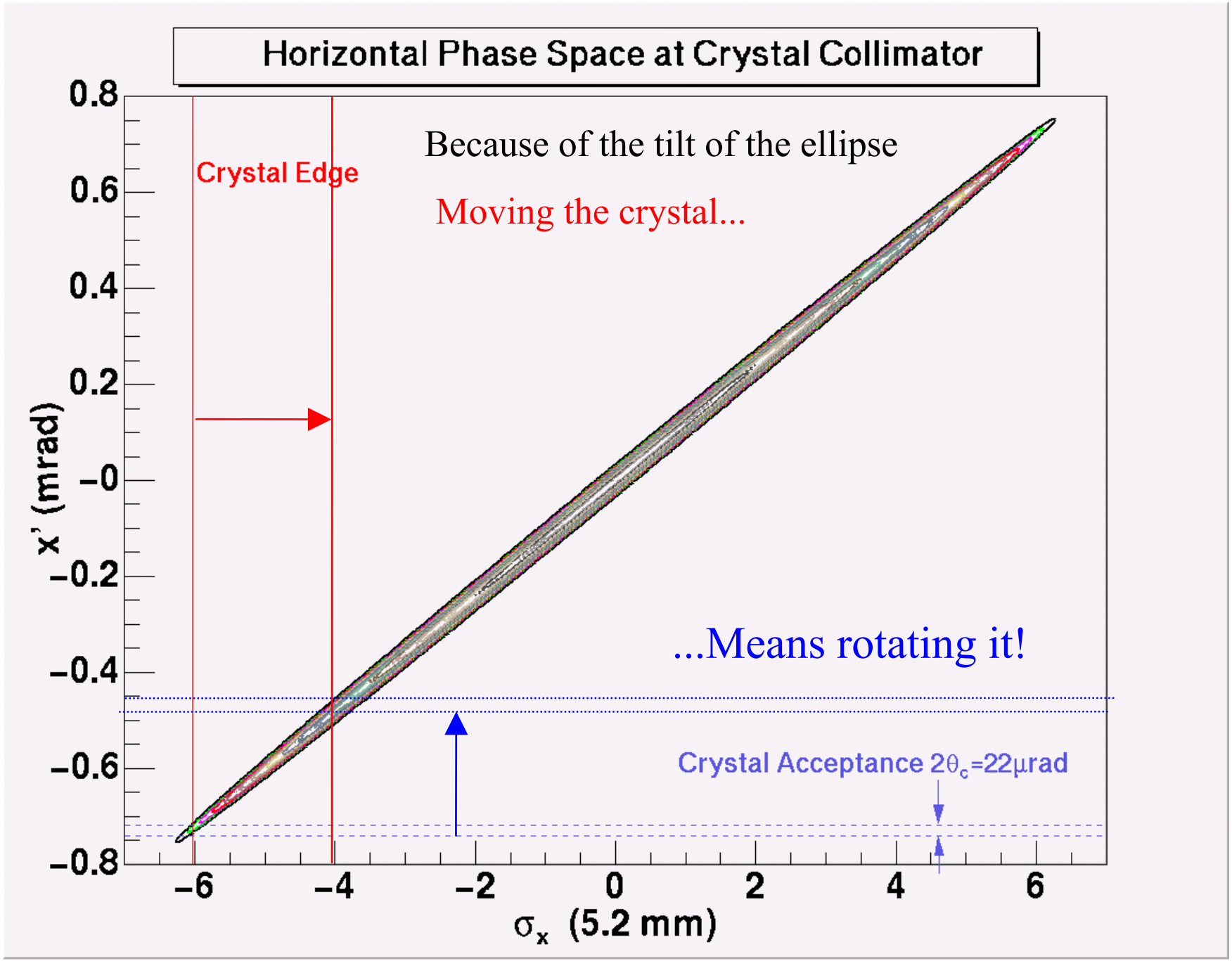
None of these are good for a collimation system.

- It is harder to operate efficiently
- Reduced channeling efficiency = reduced collimation efficiency

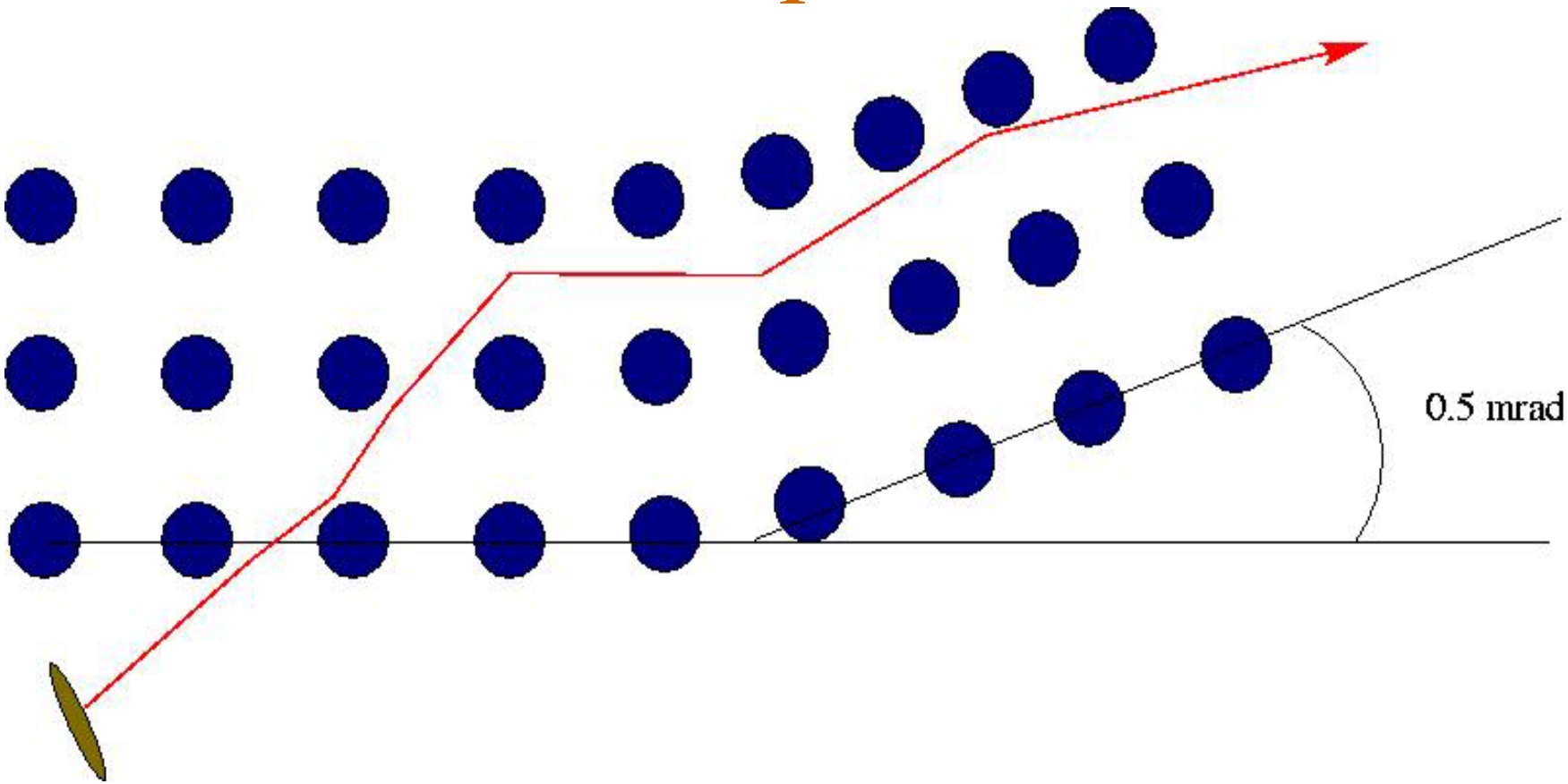
Unfortunately, all of the RHIC warm spaces have large α!

For a β =2m lattice , β = 460 m and α = -8.3 at the crystal.

For a β =1m lattice , β = 1020 m and α = -39 at the crystal.

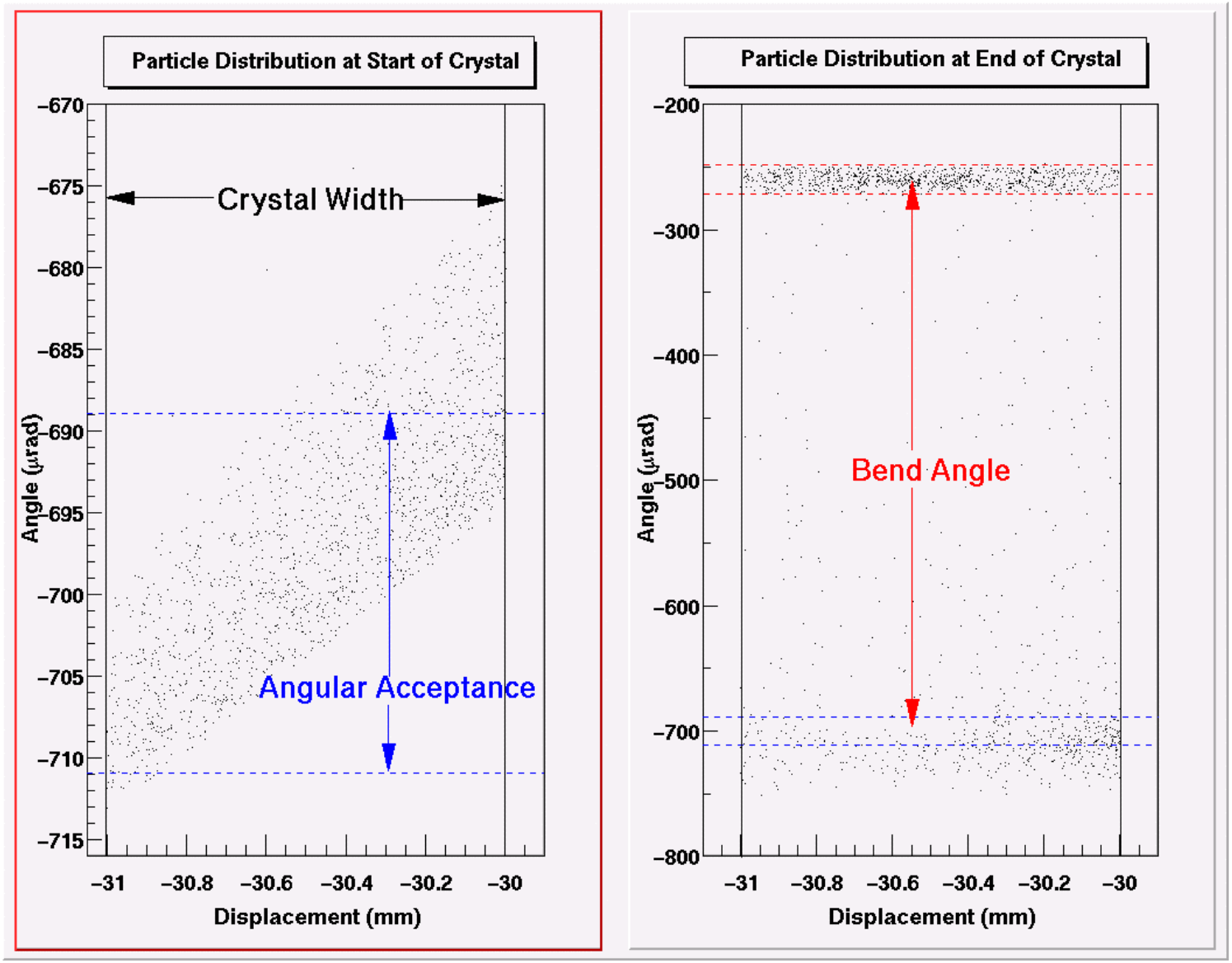

Horizontal Phase Space at Crystal Collimator
Because of the tilt of the ellipse
Crystal Edge
Moving the crystal...
...Means rotating it!
Crystal Acceptance 2θc=22μrad
x' (mrad)
σx (5.2 mm)
0.8
0.6
0.4
0.2
−0
−0.2
−0.4
−0.6
−0.8
−6
−4
−2
0
2
4
6

Volume Capture



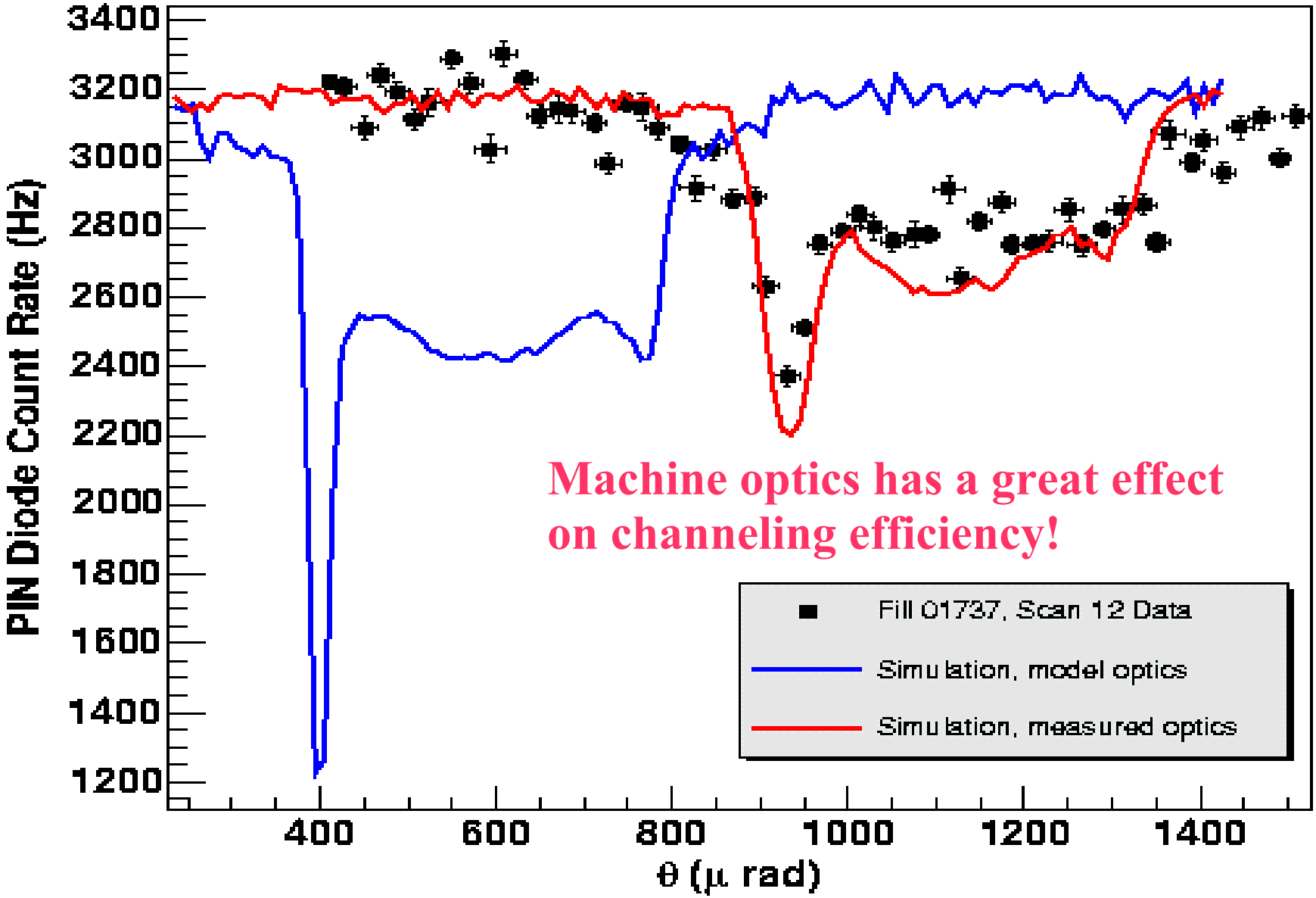
Particles that enter the crystal, not aligned to the planes, can scatter so that they have the correct angle to the planes, then channel the remaining distance in the crystal.

CATCH Code

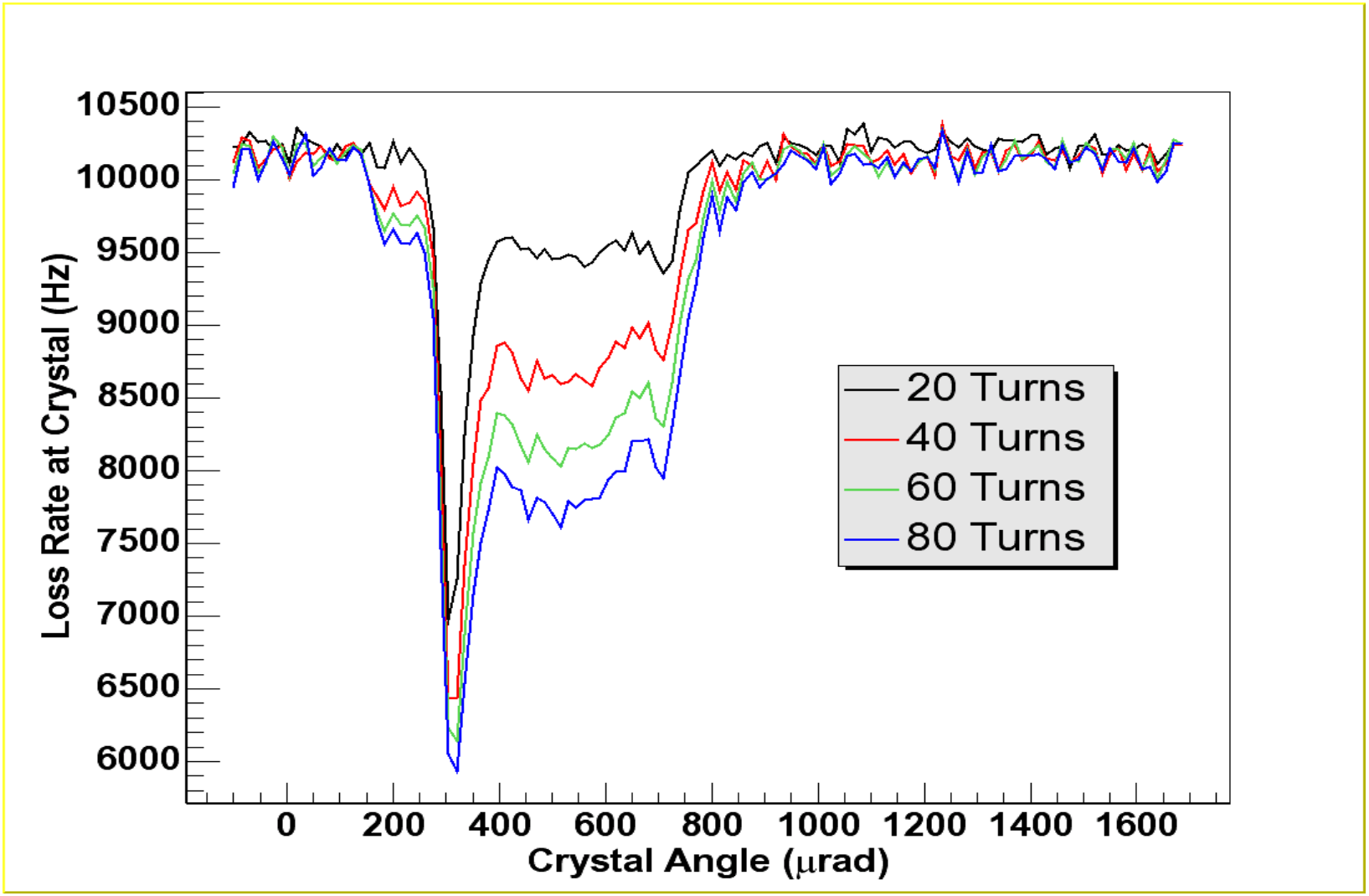


CATCH written by Valery Biryukov

Simulation of Data from RHIC 2001 Run

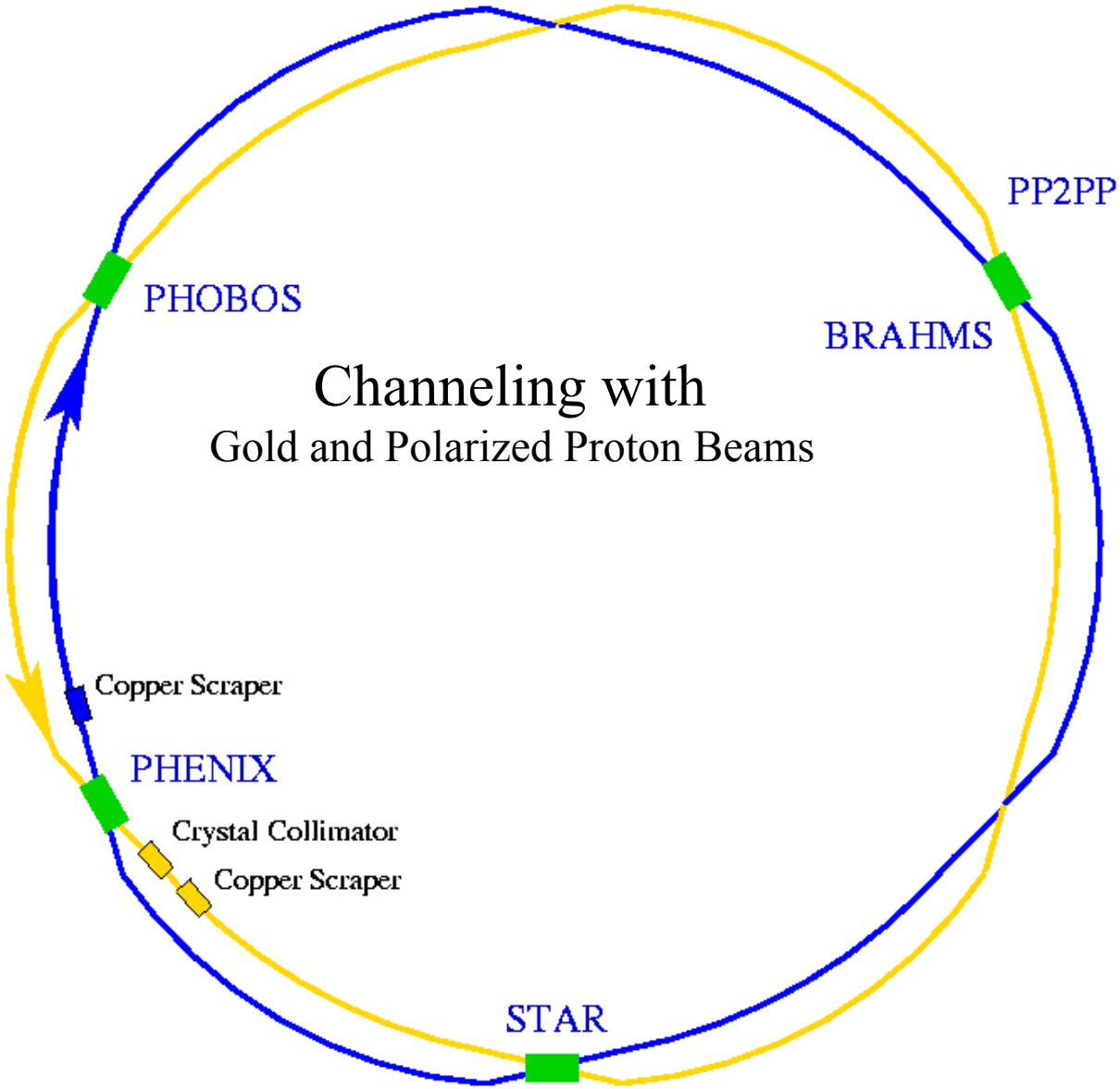


Effect of Multiple Turns on Channeling Signal

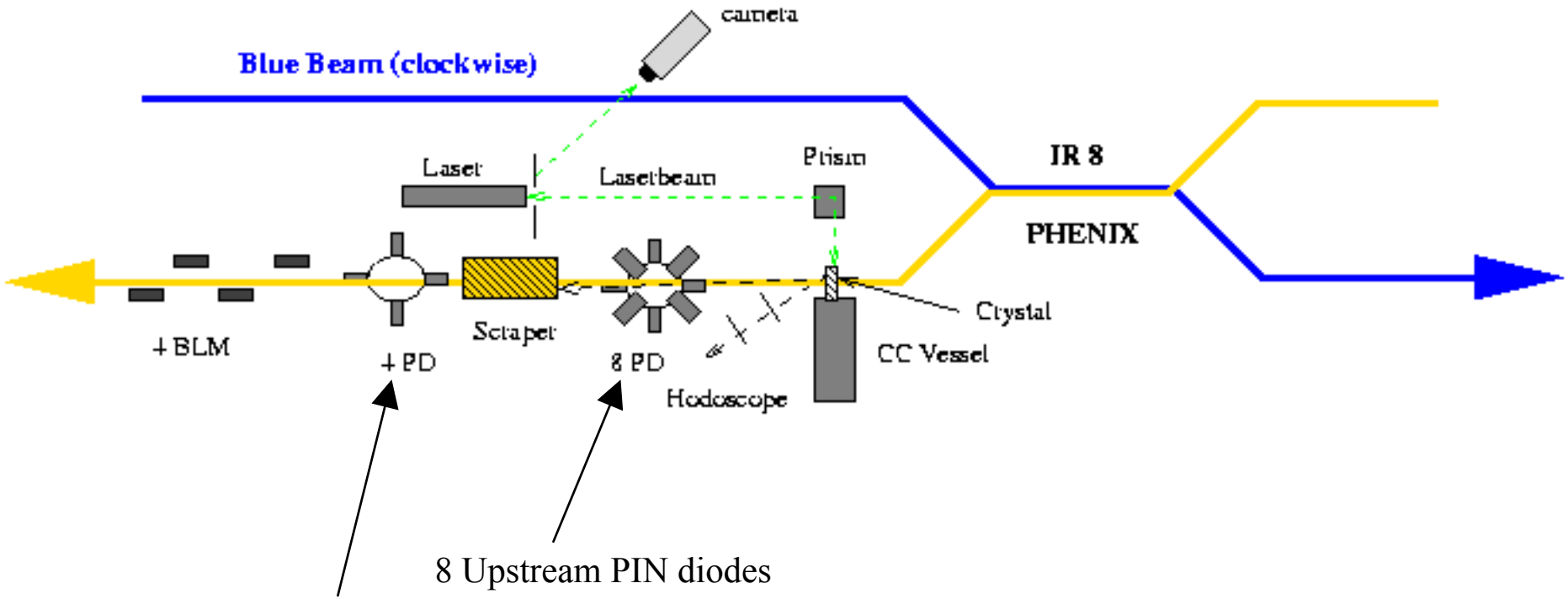


Particles not initially aligned to the crystal planes will scatter through the crystal, and can return on a subsequent turn and be properly aligned and channel. Mutliple turns can also allow the particle multiple chances to scatter in the crystal and be captured in the volume.

RHIC Overhead View



Crystal Collimator Setup

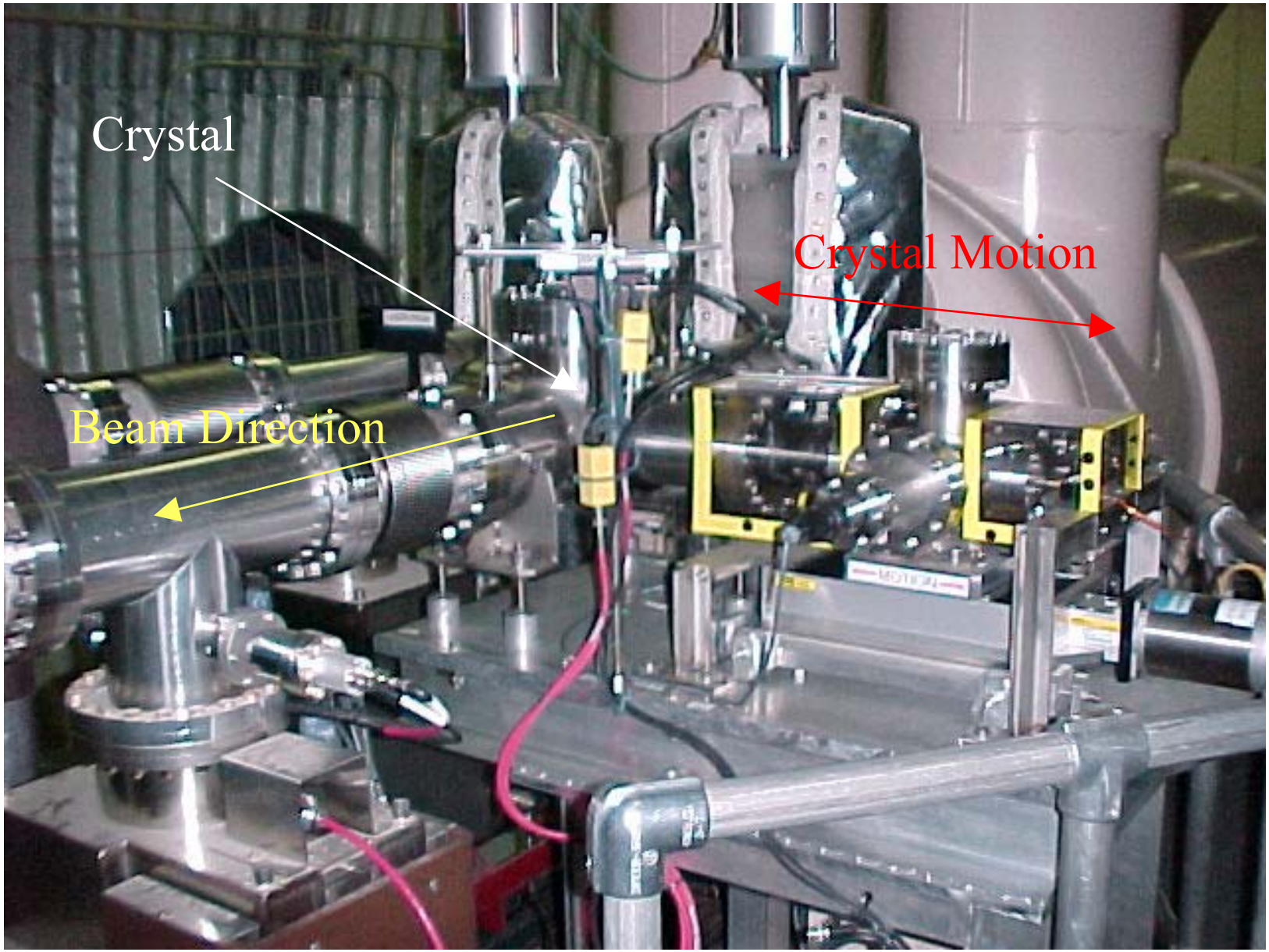


8 Upstream PIN diodes

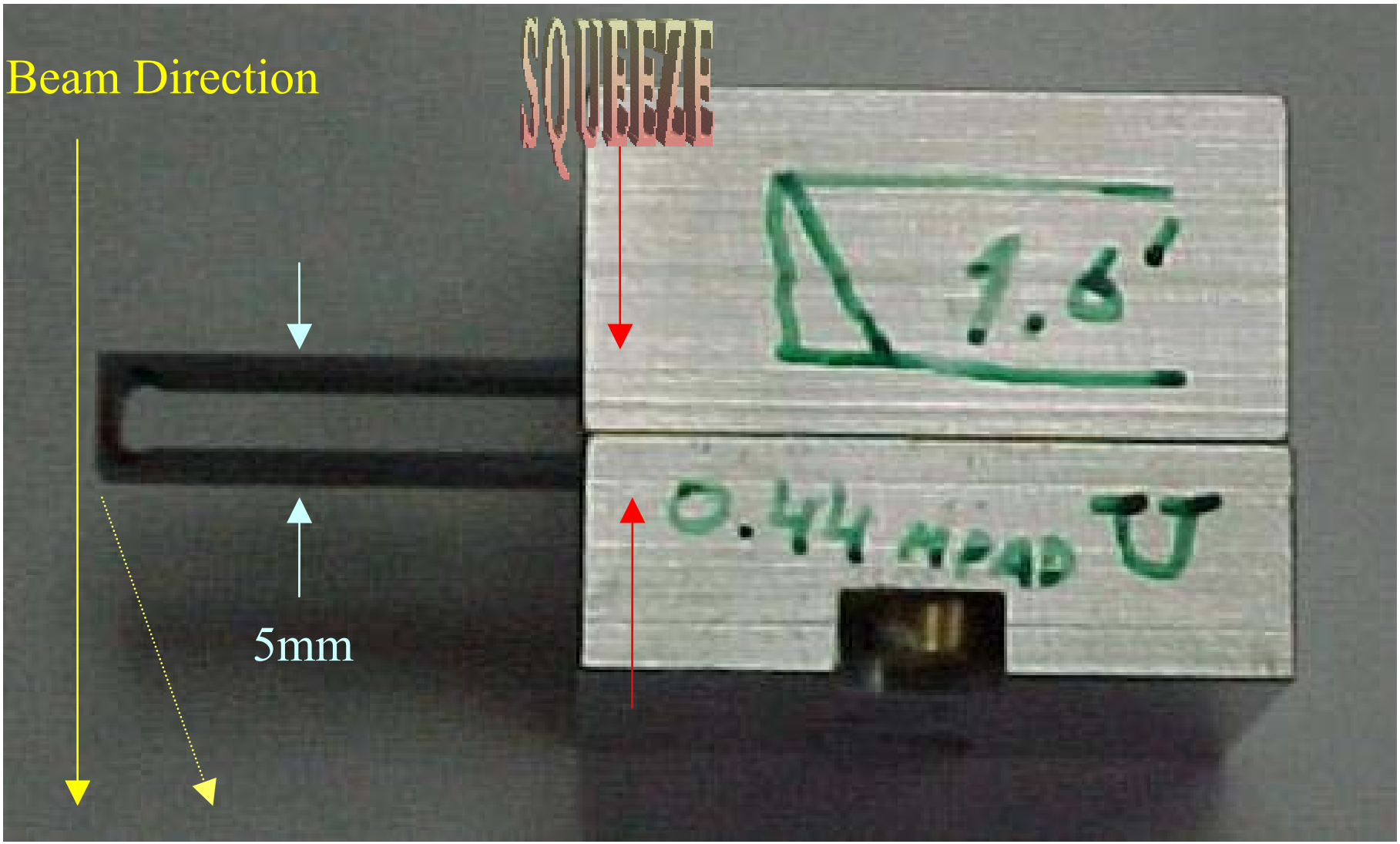
4 Downstream PIN diodes

Data fill focus on upstream PIN diodes

Crystal Vessel



Crystal

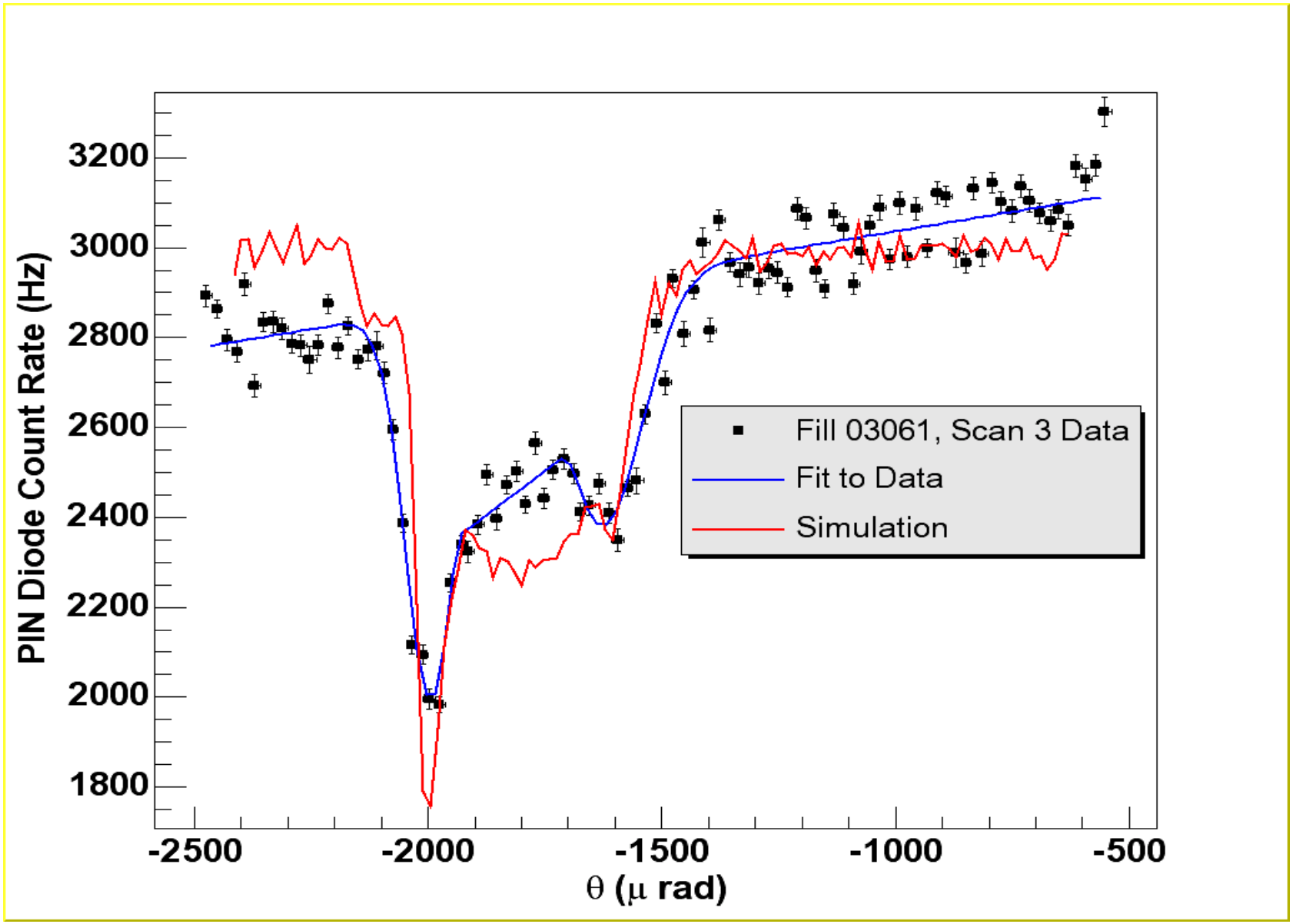


Crystal Courtesy of IHEP, Protvino

Tabulation of Data

Species	β^* (m) at PHENIX	Number of Crystal Angle Scans
Au	5	27
Au	2 (2001 Run)	24
Au	2 (2003 Run)	20
Au	1	109
p	3	119

Run 2003 Au Beam Data



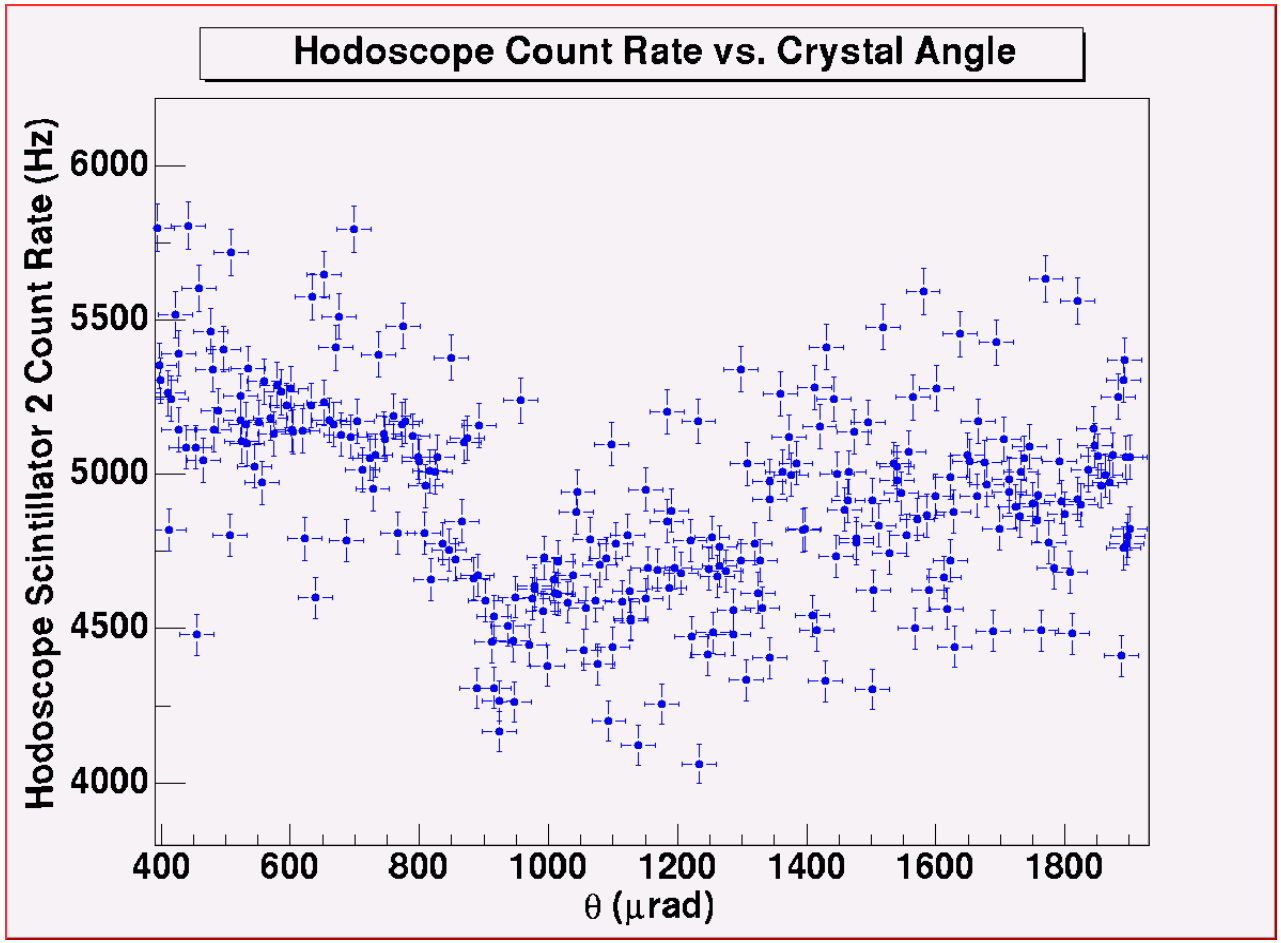
Channeling reduces the number of scattered particles.

Analysis of the data

Beam	β (m) at PHENIX	Number of Scans	$\langle\sigma_p\rangle$ (μrad)	$\langle\varepsilon\rangle$
Au	5	29	45	20
Au	2 (FY2001)	24	105	28
Au	2 (FY2003)	20	37	26
Au	1	109	69	16
p	3	119	70	26

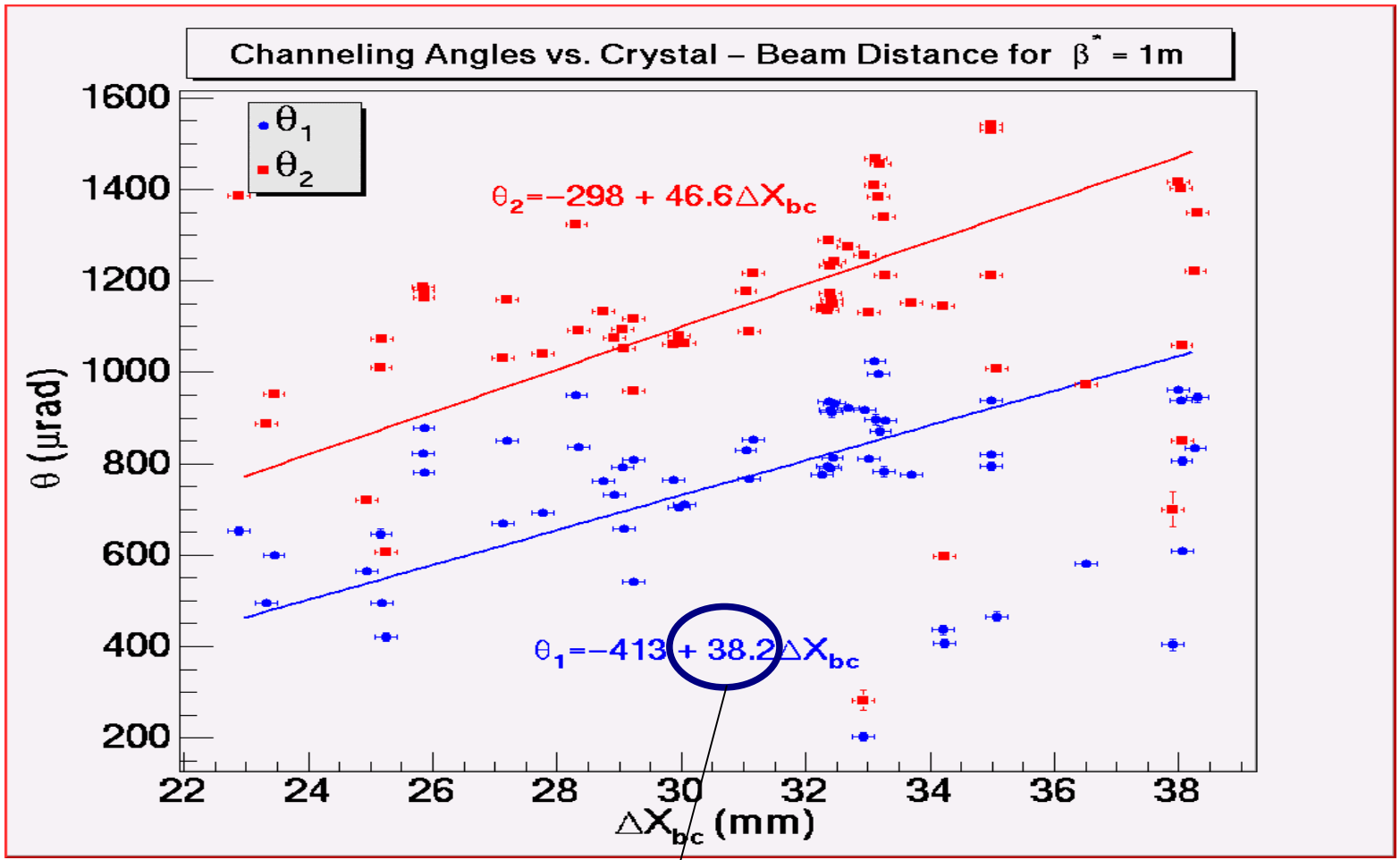
The averages quoted here are results from fitting. The fit tends to give a width wider than the data and the simulation. Simulation agrees with data.

Hodoscope signal from 2001 RHIC run.



During the shutdown, the hodoscope was inspected, and Photomultiplier Tube gains were increased. The preformance of the hodoscope improved, but gains where too low still for coincidence measurements.

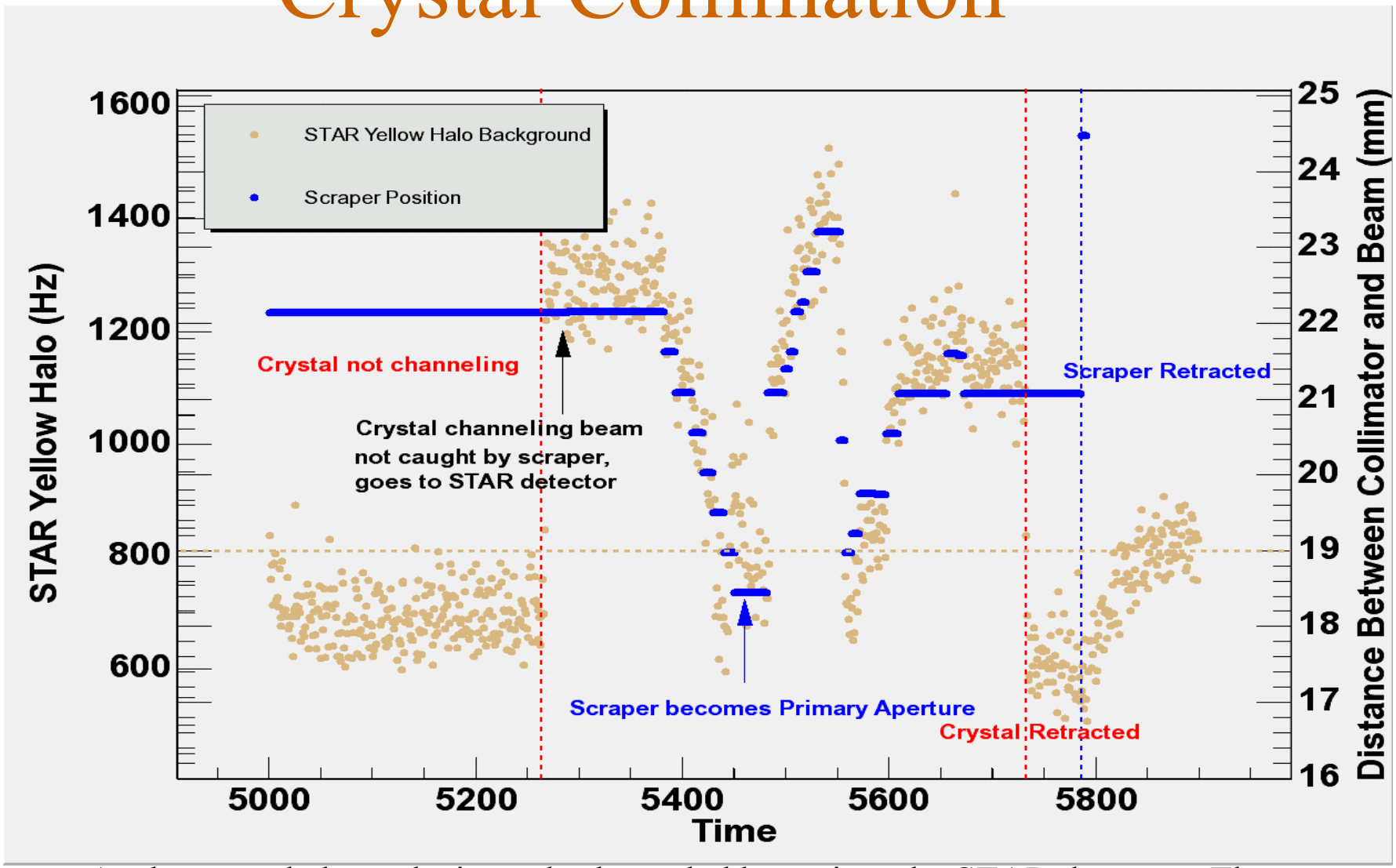
2001 Run Data



Agrees with measured Twiss Parameters.

Fitting the second peak is harder, so the expected agreement with the Twiss Parameters is less.

Crystal Collimation



As the crystal channels, it sends channeled beam into the STAR detector. The background is minimized when the scraper becomes the primary aperture!

Summary and Future Plans

- Crystal Channeling seen at RHIC
- Optics errors led to reduced channeling efficiency
- Crystal was not helpful with collimation because of these errors.
- Crystal Collimator will be replaced with a conventional collimation system.
- Crystals may be used for microbeam applications at BNL's new NSRL.